OPTIMIZATION METHODS APPLIED TO THE PRELIMINARY DESIGN OF A NAVAL AUXILIARY

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FRANK C. HOLMES

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P. MANDEL

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ABSTRACT

The technique for optimizing multidimensional functions developed in Refs. (7), (10), and (13) has been applied in this report to the preliminary design of a multimission naval auxiliary. The algorithm computes a number of effectiveness factors for each design which reflect the ship's ability to meet its specified mission requirements. These factors are then combined with the ship's twenty-five year life cycle costs in an optimization criterion which permits selection of an optimum design. Sample results obtained from the algorithm described in this report are tabulated in Tables III, IV, V, and VI.

Unfortunately, the optimization technique utilized in this report did not permit examination of results in terms of the effect on cost of each individual effectiveness factor. For this reason, the recommendation is made that for future studies of this kind, an entirely new approach should be taken as described in Section IV.

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I. INTRODUCTION

The exponential random search optimization technique utilized in Refs. (10), (13), and (7) for the preliminary design of cargo ships, tankers, and container ships respectively, is based upon searching for the set of independent design variables which describe the least cost ship satisfying a specific set of owner requirements. The optimization schemes are based upon economic criteria whose significance are readily apparent.

This same least cost procedure is not valid when designing a multimission naval ship. Costs must be balanced against the ship's ability to perform one or more military missions whose effectiveness cannot be readily measured in economic terms. The problem is one of placing a numeric value on "mission effectiveness" in such a way as to be meaningful when comparing one design with another and when matching cost with effectiveness. This is necessary in order to select one design as optimum or most cost effective.

The primary purpose of this report is the examination of one method of analyizing cost effectiveness in a multimission naval auxiliary. Dimensionless effectiveness factors are computed which reflect the ship's ability to meet its mission requirements. The sum of the factors computed is divided into the design's twenty-five year life cycle cost in an attempt to balance the effectiveness measures chosen with cost. The ship design which has the lowest numeric value of cost/effectiveness is the design selected as optimum.

In addition, programming for the computer is done with heavy emphasis placed upon the use of subroutines and readily identifiable blocks of calculations. By this means it is easy to make changes to the program that do not require major revision of the program logic. This has been adopted to keep the basic program quite general and independent of the specific design being calculated.

II PROCEDURE

The independent design variables adopted for the naval auxiliary of this report are identical with those used in Ref. (10) and are listed in Table I. The design model is patterned after the present designs of AOE's and AOR's and is described in Appendix A-1. Where the design procedure differs markedly from that in Ref. (10), justification is provided in both this section and in Appendix A.

The list of initial requirements that must be specified at the outset of the optimization procedure is given in Table II. Although this study is not concerned with how the requirements of Table II are determined, these requirements must be considered when deciding what importance or weighting to place on the four measures of effectiveness which are calculated during the computer design process. This point will be discussed in more detail when the effectiveness measures are presented later in this section.

Restrictions on the values that the independent variables of Table I can assume are imposed by stability, freeboard, strength, and powering considerations. The restrictions are as follows:

1. Beam/draft, speed-length ratio, prismatic and volumetric coefficient limitations are determined by the coverage of the Taylor's Standard Series used in the powering calculations, Ref. (9). These ranges are about as follows:

$$2.25 \leq B/T\ (XV(4)) \leq 3.75$$

Table I

Independent Ship Design Variables, XV(i)

Item	Symbol	Units	Variable
1) Displacement	Δ	long tons	XV(1)
2) Prismatic Coefficient	CP	non-dimen.	XV(2)
3) Speed-length ratio	$V/\sqrt{L}$	$\frac{\text{knots}}{\text{feet}^{1/2}}$	XV(3)
4) Beam/Draft	B/T	non-dimen.	XV(4)
5) Length/Depth	L/D	non-dimen.	XV(5)

Table II

List of Initial Requirements

1) Payload weight in long tons.
2) Maximum speed in knots.
3) Replenishment speed in knots.
4) Endurance speed in knots.
5) Endurance in nautical miles.
6) Armament weight in long tons.
7) Ship's ammunition allowance weight in long tons.
8) Aviation features weight in long tons.
9) Transfer equipment weight in long tons.
10) Liquid cargo weight as a percentage of total payload weight.
11) Cargo JP-5 as a percentage of liquid cargo weight.
12) Cargo ammunition weight as a percentage of total payload wt.
13) Dry cargo weight as a percentage of total payload weight.
14) Maximum allowable beam in feet.
15) Maximum allowable draft in feet.
16) Transfer power requirements in horsepower.

$$.77 \leq V/\sqrt{L}\ (XV(3)) \leq .[illegible]7$$

These limits on speed-length ratio allow volumetric coefficient coverage from .001 - .006. The limits are specified by formulas 1 and 2.

$$\frac{35.*XV(1)min * (XV(3)min**6)}{Vmax**6} \geq .001 \qquad (1)$$

$$\frac{35.*XV(1)max * (XV(3)max**6)}{Vmax**6} \leq .006 \qquad (2)$$

$$.48 \leq CP\ (XV(2)) \leq .70$$

In all cases, except for the upper limit on speed-length ratio, CV, and CP, the limitations imposed are not unduly restrictive as they represent more range than is normally required for conventional ship design.

2. The upper limit on L/D is imposed by strength considerations. The lower limit is the result of using data in Ref. (2) where 10 is the lowest L/D considered. These limits are:

$$10.0 \leq L/D\ (XV(5)) \leq 14.0$$

3. The limits on displacement initially represented values around those incorporated in present ship designs of the auxiliary type. However, they are also a consideration when determining CV coverage as shown in equations 1 and 2. These limits are:

$$45000 \leq \Delta\ (XV(1)) \leq 60000$$

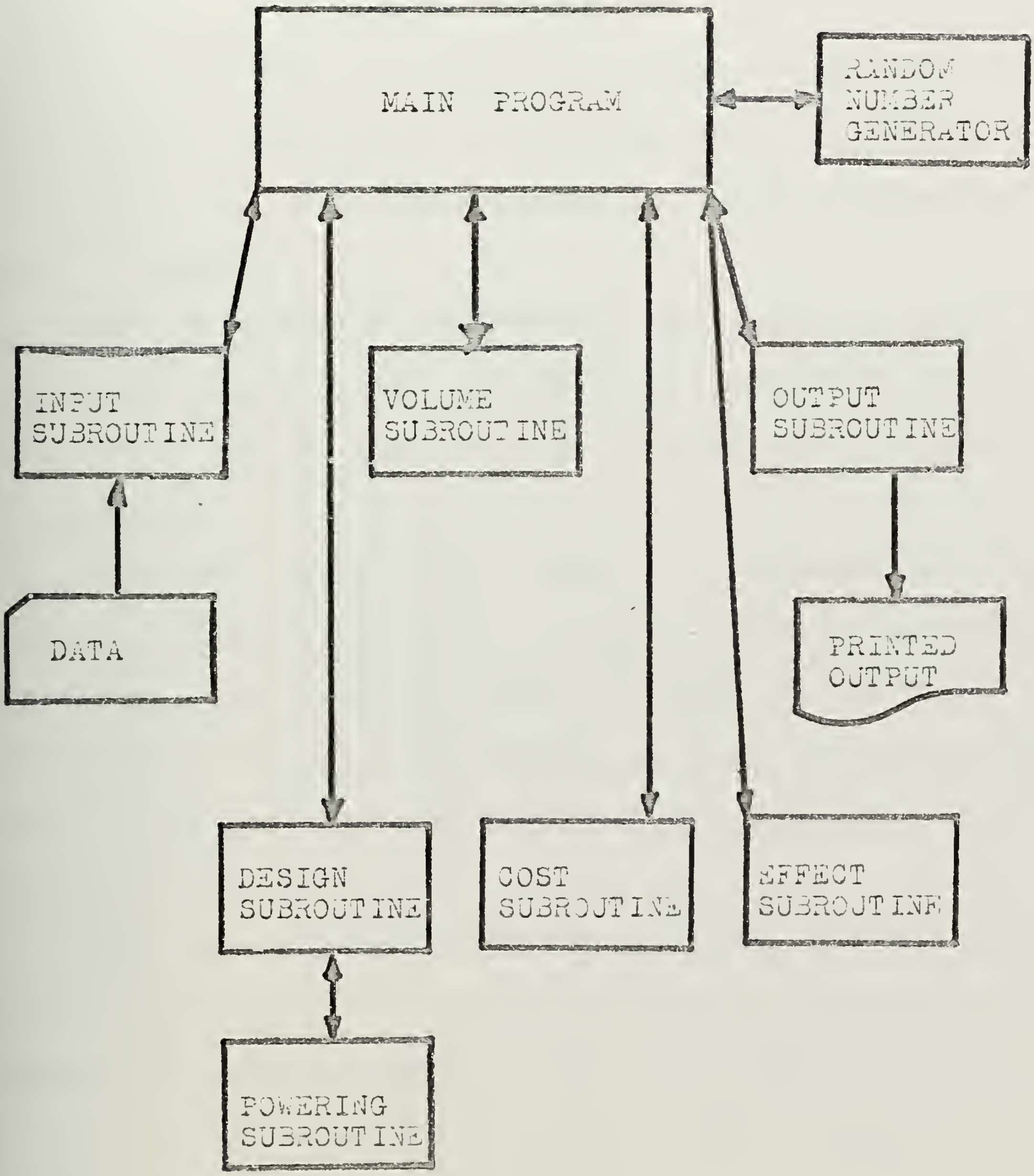
1 Program Logic

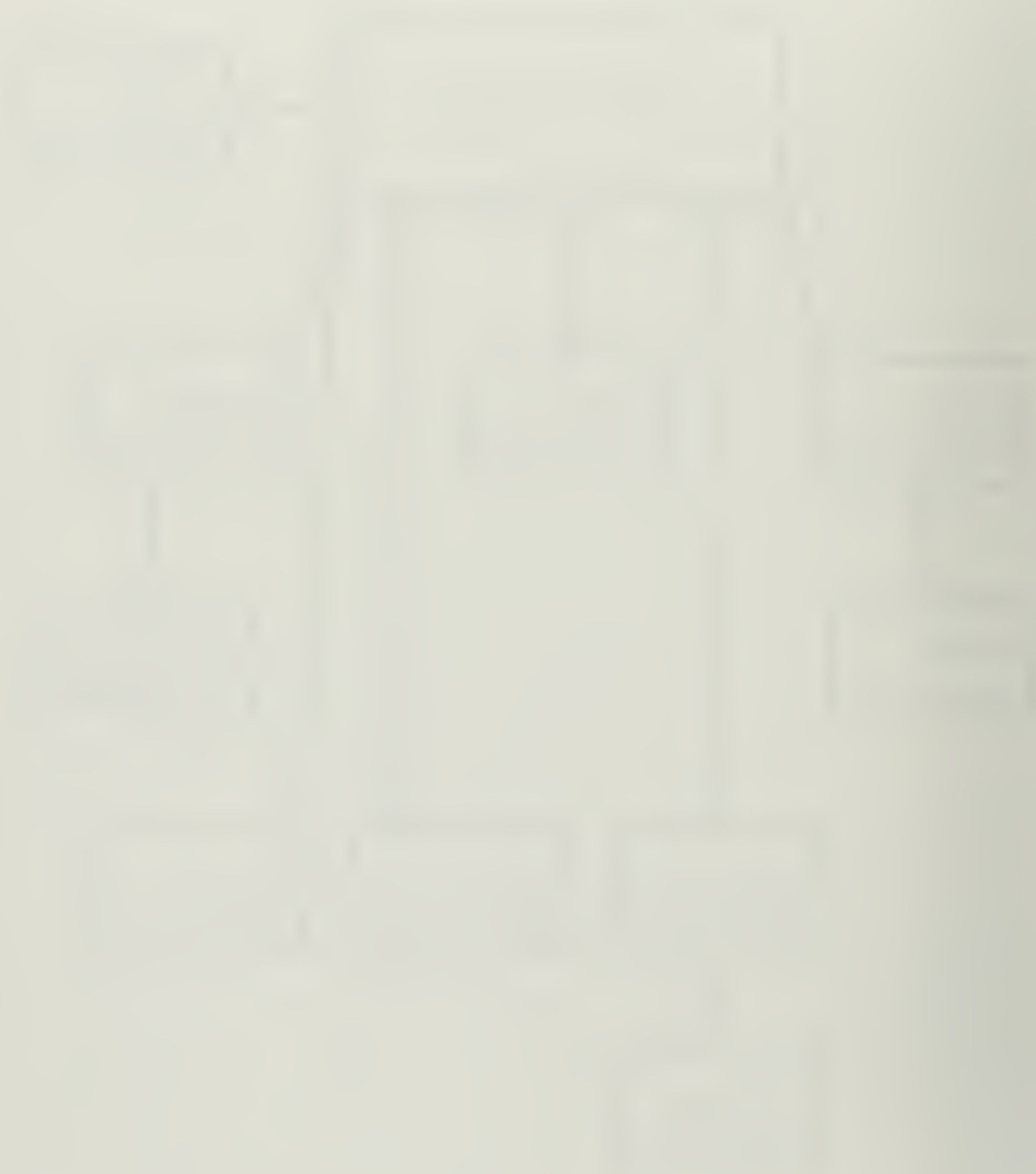
The program operates on the five design variables under the control of the main or executive routine. The general flow chart is shown in Figure I.

The main routine first calls upon the input subroutine to read in the initial data and set up the first page of output.

Figure I

General Flow Chart





The program then begins the design process in accordance with the procedure described in Ref. (10). Briefly, a design loop which includes five design cycles is originated. Each of the design cycles allows five updates per independent variable, if necessary, to obtain a satisfactory design in the particular cycle being calculated. Formula 3 is the updating equation.

```
XV(i) = XB(i) + (XMAX(i) - XMIN(i)*((2.0*RAND(0.0)-1.0)**M) (3)
```

XB(i) is the value the independent variable has in the latest best design. RAND(0.0) is the random number (a number between -1.0 and +1.0). M is the exponent in use for the particular loop in operation.

A check is made to ensure that the updated variable lies within the limits placed upon that particular variable. If the variable is outside the prescribed limits, the updating process is repeated.

After five design cycles have been completed, the loop counter is incremented by one and the design process repeats itself until the prescribed number of loops has been run. Any one of the design cycles might produce an improved design when compared to the previous best design or to the initial solution calculated.

Within each design cycle the main program first calls the design subroutine which computes a general weight balance including the actual payload weight. In addition, transverse GM is calculated and checked against a required minimum GM. This procedure is described in Appendix A-1.

If the user feels the design may be volume limited (based

upon the cargo mix initially selected), the main program then calls the volume subroutine. In this subroutine, the total internal hull volume is computed and the volume requirements for living and operating spaces are subtracted from this total. The remaining volume is available for payload. A check is made whether this remaining volume is sufficient for the actual payload carried. The required volume is based upon the payload weight previously calculated in the design subroutine. If there is not sufficient volume, the design is rejected. This procedure is described in Appendix A-2.

The main program next calls upon the cost subroutine which computes the acquisition cost, annual operating cost, and twenty-five year life cycle costs. This procedure is described in Appendix A-3.

The next subroutine called is the effectiveness subroutine which evaluates the effectiveness measures and computes "cost effectiveness" for the particular design being calculated. This variation from past optimization procedure is the salient feature of this report and is described in Section II-2.

The main program compares the return from the effectiveness subroutine with the lowest previous value of cost effectiveness. If the new design has a lower value of cost effectiveness, the design is saved and printed output is generated. Should a prior cost effectiveness be lower in value, no further action is taken with the new design. The cycle is then terminated and a fresh design cycle initiated.

Upon the completion of the last design loop, the output

subroutine is called to indicate that the last design listed is the optimum or most cost effective. (See Appendix F for sample output.)

2 Evaluation of the Effectiveness Measures

As was stated previously, the significant feature in the replenishment ship design program is the determination of a numerical method for measuring mission effectiveness. Four effectiveness indicators were chosen as being representative of a design's ability to carry out its prescribed mission. They are:

i. Comparison of actual mission fuel requirements to the traditionally required fuel necessary to steam a specified endurance distance.

ii. Comparison of freeboard required with available freeboard. This is an indication of the requirement for dry decks topside to permit personnel engaged in at-sea cargo transfer suitable working conditions.

iii. Comparison of actual payload carried to that required as an input to design.

iv. Comparison of actual volume available to that required by the calculated payload.

The first measure is significant because the ship must have sufficient bunker fuel on board to enable it to deliver its payload to the ships needing replenishment irrespective of the traditional requirement for sufficient fuel to steam a specified distance. If this fuel is not on board, the payload must be reduced or part of the payload fuel must be used as bunker fuel.

The second measure is important because topside personnel

must be able to man their replenishment stations under varied weather and sea conditions. This factor takes on greater significance as the percentage of dry cargo is increased and more direct handling of the cargo is required by the ship's crew.

The third and fourth measures selected require the design to meet the initial specifications with regard to payload. Although the algorithm permits designs of less than required payload weight, it rejects all those with inadequate volume.

These four measures are numerically evaluated by means of equations 4, 5, 6, and 7 respectively. The fuel effectiveness factor is:

$$\text{EFORFL} = ((\text{WTFUEL} - \text{EFUEL})/\text{EFUEL})*k*W \tag{4}$$

EFORFL = ship's fuel effectiveness factor.
WTFUEL = fuel weight necessary to steam the specified endurance distance.
EFUEL = fuel weight necessary to accomplish the specified mission scenario.
k = normalizing factor, described later in this section.
W = user weighting factor, described later in this section.

The replenishment scenario chosen for this study to compute EFUEL is representative but can be altered at the discretion of the user. It is described in detail in Appendix A-4. Incorporated into the replenishment scenario is the pumping capacity needed by the replenishing ship (based on present practice).

The freeboard effectiveness factor is:

$$\text{EFREE} = ((\text{FA} - \text{FMIN})/\text{FMIN})*k*W \tag{5}$$

EFREE = freeboard effectiveness factor.
FA = available freeboard.
FMIN = minimum allowable freeboard.

The available freeboard is the difference between the calculated depth and draft. The minimum allowable freeboard is based on a damage survivability requirement which is that all designs must be capable of sustaining a permanent list of 15 degrees with the addition of 5 degrees of dynamic roll without submerging the deck edge. This restriction is consistent with the information presented in Ref. (11).

The payload effectiveness factor is:

EPAYLD = ((WTPLD - WPLD)/WPLD))*k*W (6)

EPAYLD = payload effectiveness factor.
WTPLD = actual payload weight.
WPLD = required payload weight.

The actual payload weight is the weight calculated within the algorithm. The required payload weight is part of the initial input to the program.

The volume effectiveness factor is:

EVOL = ((VOLACT - VOLREQ)/VOLREQ)*k*W (7)

EVOL = volume effectiveness factor.
VOLACT = actual volume available for payload.
VOLREQ = volume required by calculated payload.

The available payload volume is that volume below the main deck remaining after meeting the ship's operating and service volume requirements. The required payload volume is the volume necessary for the payload calculated within the algorithm.

The four factors as computed in equations 4, 5, 6, and 7, are non-dimensional. They are multiplied by a normalizing factor (k) such that if a user weighting factor (W) of one is assigned to each effectiveness factor, the average value of all the effectiveness factors will be 2.0. The actual k values ut-

ilized are shown in the program listing (Appendix [illegible]) and are dependent upon the cargo mix initially selected.

The k values were originally chosen based upon a random sampling of the program output utilizing 50 design loops. An additional "write" statement was added to the algorithm so that the computed values of the effectiveness factors were written out for every successful design completed, not just those whose computed cost effectiveness was better than any previous design. Sample output was taken at the following discrete values of liquid cargo to total cargo: 92%, 80%, and 70%. For each effectiveness factor and for each cargo mix, the values obtained during the 50 loops were summed and the resultant sum was divided by the total number of results outputted for that factor. This division gave the arithmetic mean for each effectiveness factor. This mean value was a function of the cargo mix selected. In each case, a k factor was derived so that by multiplying the mean value of the effectiveness factor by the k value, the effectiveness factor takes on the value 2.0.

For example, the fuel effectiveness factor results were as follows:

% Liquid Cargo (XPCT)	Number of Results	Arith. Mean of EFORFL	k value for EFORFL = 2.0
.92	235	.372	5.37
.80	144	.441	4.54
.70	90	.518	3.87

Based on these data, the following equation was fitted relating k to XPCT:

$$k = (1.46*XPCT + 4.5)*XPCT$$

Similar K factors were derived for the payload, freeboard, and volume effectiveness factors.

The W factors are input weighting factors selected by the user. The user may decide that one effectiveness measure is more significant than the others and the ability to indicate this preference is an input parameter. The influence of weighting is demonstrated in Sections III and IV.

The four effectiveness factors computed by equations 4, 5, 6, and 7 are incorporated into an overall mission effectiveness, EFF, by means of the following equation:

$$\text{EFF} = 35. - \left| \sum \text{effectiveness factors} \right| \qquad (8)$$

The number, 35, is an arbitrary number of "effectiveness units" given to any successful design. It is based on results obtained from the algorithm as follows:

During the preliminary tests of the algorithm, the results showed that the sum of the four effectiveness factors was about 4.0 for successful designs. The designs ranged in cost from 150 to 170 million dollars. The range in costs was, therefore, 12.5 percent of the average cost for these designs. The arbitrary selection of 35 effectiveness units was made so that the change in total effectiveness was of the same order as the change in costs. That is, 4.0 is 11.5 percent of 35.

Subtracting the sum of the absolute values of the effectiveness factors in equation 8 has the effect of driving the design towards just meeting the mission requirements. With one exception, equal penalty is assigned to both falling below and surpassing the basic requirements. The only exception to this

is in the volume factor since the algorithm rejects all those designs having insufficient volume for the payload to be carried.

The optimization criterion selected for this study is the quotient of twenty-five year life cycle costs divided by EFF as computed by equation 8. That is:

COVERE = TCOST/EFF

COVERE = optimization criterion.
TCOST = twenty-five year life cycle cost.

The algorithm selects the design with the lowest value of COVERE as being the optimum design.

III RESULTS

Example results obtained by using the algorithm of this report are given in this section. Common values of the input requirements (Table II), with the exception of the cargo mix to be carried, were used for all tests. These values are given in Appendix C. The program was first used to examine the effect on design of changing the mission requirements by varying the cargo mix selected while holding the payload weight constant (Tables III and IV). Next, the effect of altering the effectiveness weighting factors was investigated (Table IV). Finally, the effect of requiring only sufficient fuel for the actual replenishment mission with no endurance fuel requirement in the traditional sense, was examined (Tables V and VI).

The ratio of the sum of dry cargo weight and cargo ammunition weight to payload weight was varied from 0.08 to 0.35. The ratio of cargo ammunition by weight to dry cargo weight was chosen to be 3.64. This figure corresponds to the cargo distribution carried in present AOE's. In all but the first tests (columns 1 and 2) listed in Table III, the algorithm was required to complete 1000 design loops. The first two tests utilized 700 loops. The exponent used in the updating mechanism was held at one for 60% of the loops, three for the next 20% of the loops, five for the next 10%, and seven for the last 10% of the loops.

The number of improvements outputted for each design prior to reaching the final design, is listed in all Tables for each final design.

Table I.I

Variation in Mission Requirements as Reflected by Changing the Cargo Distribution

Column No.	1	2	3	4
XPCT (% Liquid Cargo)	.92	.85	.80	.75
Displacement (T)	48334	49772	49758	50095
Cp	.592	.590	.543	.550
$V/\sqrt{L}$	.926	.920	.923	.921
B/T	2.279	2.511	2.465	2.544
L/D	11.23	11.31	10.93	11.90
Length (ft)	788.5	800.0	793.1	796.9
Beam (ft)	92.0	97.3	101.3	102.3
Draft (ft)	40.4	38.6	41.1	40.2
Depth (ft)	70.2	70.5	72.5	71.8
Cb	.578	.576	.527	.535
Cm	.976	.975	.972	.972
Cv	.00345	.00339	.00349	.00347
Cw	.746	.745	.727	.729
Maximum SHP	86187	82848	78143	80367
Endur. SHP	18008	19013	18252	18441
Endur. Fuel (T)	3690.06	4214.98	3817.55	3916.01
Mission Fl. (T)	2738.17	2895.67	2637.31	2614.20
Light Ship Disp.	17491	18333	18768	18992
Payload Cap. (T)	25699	25726	25713	25718
Avail. Pld. Vol.	1153076	1230829	1292599	1339178
Reqd. Pld. Vol.	1152041	1230250	1292480	1338855
GM (ft)	6.69	8.51	9.73	9.86
Complement	542	553	583	589
Costs in millions of dollars:				
Acquisition	57.54	59.46	59.65	60.00
Annual Operating	6.55	6.64	7.01	7.08
25 Year Life	159.9	163.1	169.2	170.6
No. of Impro'ments	34	22	26	21
Weighting Factors Utilized:				
Fuel	1.0	1.0	1.0	1.0
Freeboard	1.0	1.0	1.0	1.0
Payload Weight	5.0	5.0	5.0	5.0
Payload Volume	1.0	1.0	1.0	1.0

Table IV

Effect of Changes in Weighting Factors

Column No.	1	2	3	4
XPCT (% Liquid Cargo)	.70	.70	.65	.65
Displacement (T)	51214	51288	49511	51255
Cp	.634	.646	.639	.620
$V/\sqrt{L}$	.888	.905	.892	.907
B/T	2.820	3.076	2.657	2.955
L/D	13.73	13.49	13.00	12.76
Length (ft)	857.9	824.4	849.2	821.8
Beam (ft)	97.4	102.8	93.1	103.1
Draft (ft)	34.5	33.4	35.0	34.9
Depth (ft)	62.5	61.1	65.3	64.4
Cb	.621	.633	.626	.607
Cm	.979	.980	.980	.978
Cv	.00284	.00320	.00283	.00323
Cw	.767	.773	.769	.759
Maximum SHP	93547	103976	92337	96663
Endur. SHP	19643	19777	19008	19681
Endur. Fuel (T)	4539.14	4613.80	4212.31	4563.36
Mission Fl. (T)	2836.20	2953.61	2598.00	2778.30
Light Ship Disp.	19511	19437	18979	19504
Payload Cap. (T)	25678	25715	24845	25680
Avail. Pld. Vol.	1392373	1394501	1398893	1446262
Recd. Pld. Vol.	1392334	1394369	1398676	1445633
GM (ft)	10.0	13.35	6.15	11.62
Complement	564	575	559	587
Costs in millions of dollars:				
Acquisition	60.17	60.45	59.42	60.60
Annual Operating	6.81	6.99	6.74	7.07
25 Year Life	166.6	169.6	164.7	171.0
No. of Impro'ments	20	19	14	15
Weighting Factors Utilized:				
Fuel	1.0	0.5	1.0	0.5
Freeboard	1.0	0.5	1.0	0.5
Payload Weight	5.0	6.0	5.0	6.0
Payload Volume	1.0	1.0	1.0	1.0

Table V

Comparison of Designs With and Without

Endurance (10,000 mile) Fuel Requirements

Column No.	1	2	3	4
XPCT (% Liquid Cargo)	.80	.80	.75	.75
Displacement (T)	49758	48051	50095	48124
Cp	.543	.597	.550	.700
$V/\sqrt{L}$	.923	.928	.921	.896
B/T	2.465	2.767	2.544	2.667
L/D	10.93	11.84	11.90	13.68
Length (ft)	793.1	784.7	796.9	841.4
Beam (ft)	101.3	100.9	102.3	88.0
Draft (ft)	41.1	36.5	40.2	33.0
Depth (ft)	72.5	66.3	71.8	61.5
Cb	.527	.582	.534	.689
Cm	.972	.976	.972	.985
Cv	.00349	.00348	.00347	.00283
Cw	.727	.748	.729	.808
Maximum SHP	78143	91593	80367	104806
Endur. SHP	18252	18284	18441	18787
Endur. Fuel (T)	3817.55	2675.12	3916.01	2832.68
Mission Fl. (T)	2637.31	2675.12	2614.20	2832.68
Light Ship Disp.	18768	18276	18992	18290
Payload Cap. (T)	25713	25619	25718	25506
Avail. Pld. Vol.	1292599	1287816	1339178	1328236
Reqd. Pld. Vol.	1292480	1287727	1338855	1327829
GM (ft)	9.78	10.94	9.86	6.05
Complement	583	563	589	534
Costs in millions of dollars:				
Acquisition	59.65	58.80	60.00	58.30
Annual Operating	7.01	6.79	7.08	6.48
25 Year Life	169.2	164.9	170.6	159.5
No. of Impro'ments	26	23	21	18
Weighting Factors Utilized:				
Fuel	1.0	1.0	1.0	1.0
Freeboard	1.0	1.0	1.0	1.0
Payload Weight	5.0	5.0	5.0	5.0
Payload Volume	1.0	1.0	1.0	1.0

Table VI

Comparison of Designs With and Without

Endurance (10,000 mile) Fuel Requirements, Revised

Column No.	1	2	3	4
XPCT (% Liquid Cargo)	.80	.80	.65	.65
Displacement (T)	49758	48622	50992	51165
Cp	.543	.552	.549	.512
$V/\sqrt{L}$	.923	.893	.892	.855
B/T	2.465	2.323	2.393	2.554
L/D	10.93	11.93	11.53	13.29
Length (ft)	793.1	848.3	849.0	923.8
Beam (ft)	101.3	93.2	97.2	99.9
Draft (ft)	41.1	40.1	40.5	39.1
Depth (ft)	72.5	71.1	73.7	69.5
Cb	.527	.536	.534	.496
Cm	.972	.972	.972	.969
Cv	.00349	.00279	.00292	.00227
Cw	.727	.730	.729	.718
Maximum SHP	78143	74628	77690	77768
Endur. SHP	18252	19137	18718	19033
Endur. Fuel (T)	3817.55	2585.73	4060.61	2598.23
Mission Fl. (T)	2637.31	2585.73	2530.72	2598.23
Light Ship Disp.	18768	18851	19758	21399
Payload Cap. (T)	25713	25734	25696	25691
Avail. Pld. Vol.	1292599	1293568	1446591	1446649
Reqd. Pld. Vol.	1292480	1293528	1446541	1446265
GM (ft)	9.78	6.50	5.90	10.25
Complement	583	582	614	614
Costs in millions of dollars:				
Acquisition	59.65	59.30	61.02	63.32
Annual Operating	7.01	7.01	7.34	7.34
25 Year Life	169.2	168.7	175.7	178.0
No. of Impro'ments	26	20	16	9
Weighting Factors Utilized:				
Fuel	1.0	1.0	0.5	0.5
Freeboard	1.0	1.0	0.5	0.5
Payload Weight	5.0	5.0	6.0	6.0
Payload Volume	1.0	1.0	1.0	1.0

V. DISCUSSION OF RESULTS

The design listed in column 1 of Table III has the same cargo distribution as AOE-3 and as result is similar to the existing design. The AOE-3 is slightly larger in size (4000 tons of full load displacement) but this is as expected because the algorithm used in this study drives the final design towards just meeting its volume requirements whereas this was not necessarily an objective in the design of the existing ship. The similarity indicates that the design model of the algoritm is adequate for designing ships of the AOE-type.

All the designs listed in Table III demonstrate the expected result that the optimum design, as selected by the program, increases in dimension, displacement, and cost as the payload volume requirements are increased (increasing the percentage of dry cargo) while holding the payload weight constant. In replenishment ship design, this is also expected because the manning requirement increases as the percentage of dry cargo carried increases. The manning level increase is due to the fact that more personnel are required for transfering dry cargo than liquid cargo as more direct handling of dry cargo is called for during cargo transfer. The additional personnel occupy more space within the ship and therefore, they too, add to the need for increased ship size.

It was expected that the designs listed in columns 1 and 3 of Table IV would follow the same trend as the designs listed in Table III. However, due to their much larger percentage of dry

cargo, the weighting factors used in the Table III designs were no longer applicable. The designs listed in Columns 2 and 4 of of Table IV show that by reducing the weighting factors on the fuel and freeboard effectiveness measures (less penalty for excess or insufficient fuel and freeboard as the designs carry more dry cargo) and by increasing the payload weighting factor, the designs in these columns follow the pattern established in Table III. That is, increasing volume requirements promote designs of increased dimension, displacement, and cost.

The replenishment scenario used in computing mission fuel requirements, Appendix A-4, is based on a particular liquid cargo transfer rate given in Appendix A-4. The mission fuel requirements are, therefore, sensitive to changes in the amount of liquid cargo carried. However, the mission fuel requirements were not, unfortunately, made sensitive to changes in transfer time occurring as a result of the additional bulk cargo to be transfered. Therefore, for the designs of Columns 2, 3, and 4 of Table III and for all the designs of Table IV, less penalty should be assigned if the mission fuel and the endurance fuel requirements (see equation 4) are not the same. This may be accomplished by reducing the weighting factor as is done for the designs in Columns 2 and 4 of Table IV.

Reduction of the freeboard weighting factor in Columns 2 and 4 of Table IV allows for more freeboard in the final design which is necessary in volume limited designs. Finally, the increase in the payload weighting factor increases the importance of meeting the initial payload weight requirement by assigning

more penalty to falling below or surpassing the prescribed payload weight. The payloads in the designs of Columns 2 and 4 are therefore more nearly equal to the initial requirements than are the payloads listed for the designs of Columns 1 and 3.

It was expected that the results of Table V would show that by eliminating the requirement to carry a prescribed amount of endurance fuel regardless of the mission, the resultant designs would be reduced in dimension, displacement, and cost. The expected result is not apparent in this Table because the manning levels computed for designs 1 and 2 and for designs 3 and 4 (each set having the same cargo distribution) are not the same. The equation used to compute manning in these tests was dependent on ship size (cubic number) and the installed S.H.P.. As a result, the manning levels varried even when the basic cargo requirements were the same. This inconsistency within the algorithm greatly affected the costs for these designs and therefore invalidated the comparisons.

A change in the manning equation which made it dependent only upon the prescribed cargo distribution corrected the error present in the results of Table V (see Appendix A-1, equation 10). This new equation is used in the computations for the designs listed in Table VI. In this Table, the comparative designs in Columns 1 and 2 did show some reduction in dimension, displacement, and cost when the endurance fuel requirement was removed. The result was expected but the importance of changing the endurance fuel requirement seems minimal. A total savings in acquisition cost of slightly under $300,000 was all that was

achieved. This small savings does not appear significant when compared to the loss in operational flexibility due to the decreased amount of bunker fuel on board.

The designs listed in Columns 3 and 4 of Table VI do not show the same comparative results as do the designs of Columns 1 and 2. As indicated, there were far fewer improvements made in the designs of Columns 3 and 4 during the 1000 design loops than in the designs of Columns 1 and 2. It is possible that additional design loops would result in designs consistent with those in Column 1 and 2 of this Table.

It is even more likely that for the 35% dry cargo designs of Columns 3 and 4 that the input constraints placed upon the design variables are too restrictive. The constraints were held constant for all the tests made during this study and they could have been unduly restrictive for designs carrying more than 25% dry cargo. The constraints are input parameters and can be readily changed as long as the restrictions imposed by equations 1 and 2 are enforced.

The results of all the tests made for this study, particularly the weighting factor tests listed in Table IV, have demonstrated the need for a difinitive means of measuring the effect on life cycle costs of a specified change in the effectiveness factors. The algorithm has provision for weighting the effectiveness factors but unfortunately, the user does not know a priori what weighting to use. As there is no way of determining the sensitivity of the design to individual changes in the effectiveness factors, the user may only guess what the cor-

rect weighting factors should be.

As a result of this inadequacy within the present algorithm, no conclusion may be drawn as to whether or not the final designs outputted are meaningful optima.

It appears that a better approach must be sought to optimizing the design of ships whose effectiveness is measured in non-economic terms. It would be useful to be able to determine the sensitivity of life cycle costs to changes in the individual effectiveness factors. One means of accomplishing this task would be an algorithm which incorporates both the exponential randon search technique and the parametric search technique. The effectiveness factors desired could be included as input as are the mission requirements of Table II. A parametric search could be made begining with the input values of the effectiveness factors and then incrementing the search through any predetermined range of values for each effectiveness factor. The additional programing necessary would only require that a series of imbedded "DO loops" be placed within the present algorithm and the current effectiveness calculations removed.

The currently utilized exponential random search could be used to find the optimum design for each set of specified effectiveness parameters. The results of such an algorithm would indicate to the user what each change in the individual effectiveness factors cost. With this knowledge, decisions concerning the desired level for each effectiveness factor would be much easier to reach.

The usefulness of the programing approach taken was illus-

trated repeatedly during the progress of this study. For example, program alterations were necessary to compute Tables V and VI. Again, alterations were necessary to incorporate a new manning equation. The first change was a relatively simple matter of shifting calculation blocks from the effectiveness subroutine to the design subroutine. This had the effect of replacing the previously utilized endurance fuel equation of the design algorithm with the mission fuel calculations and renaming the result so as to be consistent with the variable names used originally. In the second case, a card change was all that was required to institute the new manning formulation. Other refinements to the algorithm, necessary during the course of this study, were also facilitated by the programing technique utilized.

V CONCLUSIONS

1. The design model used in the algorithm of this report provides designs consistent with the parent ships from which the design model was derived.
2. No conclusion may be drawn with regard to the effectiveness factors chosen for this study as it has not been possible to determine accurately, their individual effect on design or cost.
3. It appears that the multimission ship optimization problem requires an algorithm incorporating both the exponential random search and the parametric search technique.
4. Increasing volume requirements with the same payload weight requirement results in designs of increased dimension, displacement, and cost.
5. Eliminating the endurance fuel requirement for the replenishment ship of this report does not institute significant savings in ship cost while it may reduce the flexibility of the final design.
6. The programing techniques utilized in this report provide a significant advantage to the programmer when alterations become necessary to the algorithm.

VI RECOMMENDATIONS

The following is a list of additional investigations considered to be of paramount importance in future studies of this kind:

1. Other effectiveness parameters should be investigated. The four factors used in this report are not necessarily exhaustive of the possible measures that may be evaluated. In particular, other means of evaluating the requirements for the replenishment mission may be necessary to reflect the bulk cargo transfer rate.
2. The entire algorithm should be revised to incorporate the parametric search technique in conjunction with the currently utilized exponential random search technique. This is necessary in order to examine in detail the individual effect of each effectiveness parameter on design and cost.
3. An investigation should be made to determine the effect that the initial constraints have upon the final design selected. In particular, the constraints used in this report should be changed for the more volume limited designs investigated (those designs with more than 25% bulk cargo) to determine if the constraints used unduly restricted the results obtained.

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VII APPENDIX

APPENDIX A

Details of Procedure

1. Design Subroutine

The design algorithm calculates the weight breakdown for each design. This is done by computing weights for the seven standard weight groups, margin weight, light ship displacement, operating fluids and stores weight, and the actual payload. In addition, minimum and actual GM are computed within this subroutine.

The following equations are used to compute the weights of the seven weight groups. The equations are patterned on the designs given in Refs. (5) and (12), with the exception of weight group one which is modeled on data presented in Ref. (2).

a. Hull Structure:

```
WTGRP(1) = (.206 + .003*(XV(5)-14.))*CN + .011*(CN-50000.)
           + 6250.*CB +375.*(XV(5)-14.) - 2000.
```

b. Propulsion: (based on installed S.H.P.)

```
WTGRP(2) = .00471*SHP + 1001.
```

c. Electric Plant: (based on installed S.H.P.)

```
WTGRP(3) = .306*(SHP/1000.) +338.4
```

d. Communications and Control:

i. Interior communications systems:

```
SG401 = .312*(CN/1000.) + 10.64
```

ii. Countermeasures and ship protective system:

```
SG403 = .3165*(CN/1000.) + 30.49
```

iii. Communications and control spare parts:

```
SG450 = .00175*(SG401 + SG403) +4.0
```

iv. Total:

WTGRP(4) = 145.5 +SG401 + SG403 + SG450

145.5 represents a fixed weight for electronics systems whose dimensions are not dependent upon the particular design. This number also includes navigational systems and associated equipment.

e. Auxiliary equipment:

i. Equipment dependent on ship size:

SGLBD = 91.1*SQRT(CN/1000.)

ii. Equipment dependent on the amount of cargo oil:

SGPLD = .00356*XPCT*WPLD

iii. Equipment dependent on plant size:

SGSHP = 40.52*SQRT(SHP/1000.)

iv. Total plus 9% for repair parts:

WTGRP(5) = 1.09*(SGLBD + SGPLD + SGSHP + TRANWT)

TRANWT is the input weight for required transfer equipment.

f. Outfit: (based on ship size)

WTGRP(6) = 25.5*(CN/1000.) + 174.

g. Armament: (input parameter)

WTGRP(7) = ARMENT

Margin weight is computed as four percent of the sum of the above weights. Light ship displacement is the sum of the seven weight groups plus the margin weight.

The algorithm then computes crew size dependent upon installed S.H.P. and ship size. This was found to be inadequate when making test calculations and an equation based upon the cargo mix selected was substituted in the final computations.

The new equation is equation 10.

COMP = 542. + ((16.75*(PCTJP5 + PCTA[illegible])*WPLD)/2125.)   (10)

This equation reflects the need for more crew when the ship carries more bulk cargo which would require more cargo handlers. If substantial change were made in the armament of the ship, the electronics suit, or the engineering plant, the fixed number of 542 men would have to be changed also.

With the results of equation 10, the number of officers is computed as 5.5 percent of the complement, chief petty officers as 4.5 percent, and the crew makes up the remaining 90 percent of the total complement.

Using data found in Ref. (6), the complement weight is calculated as follows:

WTCOMP = (NOFF*400 + NCPO*330 + NCREW*230)/2240

The stores weight and the weight for potable water are computed based on the previously calculated complement size and the necessary stowage factors.

WTSTOR = .375*COMP

WTPTWR = .15*COMP

Reserve feed water weight and the weight for lubrication oil are both computed based on the installed S.H.P..

WTFDWR = 2.18*(SHP/1000.)

WTLBOL = .25*(SHP/1000.)

Ship's fuel weight is determined based on the requirement for the ship to have the ability to steam 10,000 nautical miles at its prescribed endurance speed. The specific fuel rate data was found in Ref. (2).

WTFUEL = 5[illegible].*(SHP/1000.) - 571[illegible].

After these weights have been added to the light ship displacement, the sum is subtracted from the ship's full load displacement to give the actual payload carried. This weight must be greater than seventy-five percent of the required payload weight.

Minimum GM is determined as five percent of the beam. In order to calculate the actual GM, vertical moments based on a percent of the designed depth are computed to fix the vertical center of gravity. BM and KG are calculated in accordance with standard formulas found in Ref. (8).

2. Volume Subroutine

The volume algorithm first makes a calculation of total internal volume below the main deck. This done by computing a pseudo-midship's coefficient based on the beam and depth rather than draft. Volume is then determined using the new midship's coefficient, Cp, and the previously computed cubic number.

VOL = CMX*XV(2)*CN*100.

CN = the cubic number
XV(2) = Cp
CMX = pseudo-midship's coefficient

This ia a conservative estimate of internal volume as no provision is made for shear or flair.

From this total volume is subtracted the volume required for living and operating spaces below the main deck. Living space volume, sanitary space volume, and stores volume are computed based on data given in Ref. (6). They are all dependent upon the complement required by the particular design. The

equations used are shown in Appendix B, Volume Subroutine, Boxes 2 through 6.

Volumes for passageways, uptakes, and engineering spaces are patterned after the present designs for AOE-1 and AOR-1.

Passageway volume is computed as ten percent of the ship's cubic number. This allows for the dependence passageway volume has upon the ship's size.

Uptake volume is taken as 30,000 cubic feet plus a factor dependent upon the installed plant size. Equation 11 is used.

$$VUPTK = 30000. + 100.*(SHP/1000.) \qquad (11)$$

The volume required for the steering gear room is determined as 5000 cubic feet plus a factor dependent upon the installed S.H.P. (Equation 12).

$$VSTGRR = 5000. + 26.*(SHP/1000.) \qquad (12)$$

Engineering space volume is computed assuming fixed breadth and height of the machinery box with the length dependent upon the installed S.H.P.. The breadth used is 53 feet and the clear deck height is 45 feet (Equation 13).

$$VOLENG = (SHP/1000. + 40.)*2380. \qquad (13)$$

In addition to these computed volumes which are based on ship size, complement, and/or installed S.H.P., fixed volume is included for shop and office space. The volume required by these spaces may be regarded as fixed regardless of the design being calculated within the range of interest.

After the sum of these volumes has been subtracted from the previously determined internal volume, the remaining volume is considered available for carrying payload. Required

payload volume is computed based on the calculated payload weight and the initial cargo mix selected. These volumes are further dependent upon the stowage factors initially selected by the user.

The available and required volumes are compared. If there is insufficient volume for the calculated payload weight, the design is rejected. If there is sufficient volume, the algorithm returns to the main routine in order to continue the design process.

3. Cost Subroutine

The ship's acquisition cost, annual operating cost, and twenty-five year life cycle costs are calculated within this subroutine in accordance with Ref. (1). The base cost of each design is determined based on a fixed cost per weight group ton. The charges are assumed to reflect material, labor, and overhead costs at the construction site. They are:

a. Weight Group 1-----$900/Ton
b. Weight Group 2----$5000/Ton
c. Weight Group 3----$8000/Ton
d. Weight Group 4----$9000/Ton
e. Weight Group 5----$5000/Ton
f. Weight Group 6----$4000/Ton
g. Weight Group 7---$50000/Ton

These costs may be changed readily within the algorithm to reflect new information available to the user.

To the sum of these computed costs, percentages are added for margin, design and construction, escalation, profit, change orders, post delivery costs, quality assurance, and Navy shock requirements. The total of these costs determines acquisition cost. The percentages used are:

a. Margin------------------------[illegible]
b. Design and Construction--1%
c. Escalation-----------------3%
d. Profit---------------------4%
e. Change Orders--------------1%
f. Post Delivery Costs--------½%
g. Quality Assurance----------1%
h. Shock Requirements---------1%

In the same manner that base costs may be changed, these percentages may also easily be changed to reflect new information dependent upon prevailing rates in the shipbuilding industry.

In order to estimate annual operating costs, the following empirical relationship is utilized.

ANOPCT = (540. + 11.1*COMP)*1000.

This relationship was provided to the author by Mr. George Kerr, Surface Ships Design Branch, NAVSEC, Washington, D. C.. It reflects the fact that for estimating purposes, the complement assigned to a ship is the most significant factor in annual costs.

Twenty-five year life cycle costs are estimated by discounting the annual operating costs at four percent for 25 years and to this figure adding the computed acquisition cost.

4. Replenishment Scenario

The mission fuel requirements for each design are determined by use of the following average replenishment scenario.

Every thirty-six hours, the AOX designed by the algorithm is required to replenish a task group made up of the following ships, at the pumping rate specified, and at the along-side time specified. This is done so that the total amount of cargo transfered may be determined for the task group chosen.

Task Group	Pumping Rate	Along-side Time
1 Attack Carrier	16000 gal./min.	45 min.
6 Destroyer Types	2000 gal./min.	30 min.
1 Non-carrier Heavy	5000 gal./min.	45 min.

This gives the total transfered cargo oil per replenishment.

Totals	Gallons Transferred
1 Attack Carrier @ 45 min.	720,000 gal.
3 DD's @ 30 min. (2 along-side together) 90 min.	360,000 gal.
1 Heavy @ 45 min.	225,000 gal.

These totals result in 1,305,000 gallons of cargo oil being transferred in three hours. This equals 4591 tons per replenishment stop as computed in the following relationship.

$$\frac{1,305,000 \text{ gal.}}{7.48 \text{ gal./ft}^3 \times 38 \text{ ft}^3\text{/ton}} = 4591 \text{ tons}$$

By further assuming that the delivery ship steams 1000 nautical miles at twenty knots to and from the replenishment area, steams 500 nautical miles at its endurance speed between replenishments, and steams three hours during each replenishment at seventeen knots, equation 14 may be derived.

$$EFUEL = TRFUEL + BTFUEL + REFUEL$$

TRFUEL = the fuel consumed during transit to and from the replenishment area.
BTFUEL = the fuel consumed between replenishments
REFUEL = the fuel consumed during replenishment.

These figures are determined by knowing what S.H.P. is required at the specific speed, the specific fuel rate, and the number of replenishments to be made. The number of replenishments is determined by dividing the cargo fuel weight previously calculated by 4591 tons, the weight of cargo fuel transferred at each replenishment. The final equations used are shown in the program listings, Appendix E, and are based on specific fuel

rate data in Ref. ([illegible]).

This scenario implys that the fuel transfer rate governs along-side time. For this study, and the cargo mixes evaluated, this appears to be a valid assumption.

[illegible]

Program Documentation

1. Variable Definition

The first list is a list of all variable names held within common storage. The remaining variable names are listed by the subroutines in which they appear.

Name	Dimension	Definition
ACCOST	-	Computed value of acquisition cost.
ANOPCT	-	Computed value of annual operating cost.
ARMENT	-	Input value of armament weight.
B	-	Computed value of ship's beam.
BM	-	Computed value of metacentric radius.
BMAX	-	Input value of maximum allowable beam.
CB	-	Computed value of block coefficient.
CM	-	Computed value of midship's coefficient.
CN	-	Computed value of cubic number.
COMP	-	Computed number in ship's complement.
COVERE	-	Computed value of "cost effectiveness".
CR	6210	Array which stores residual resistance coefficients for powering subroutine.
CV	-	Computed value of volumetric coefficient.
CW	-	Computed value of waterplane coefficient.
D	-	Computed value of ship's depth.
DISPLS	-	Computed value of light ship displacement.
EFORFL	-	Computed value of fuel effectiveness factor.

Name	Dimension	Definition
EFRBL	-	Computed value of freeboard effectiveness factor.
EFUEL	-	Computed amount of mission fuel required.
EPAYLD	-	Computed value of payload effectiveness factor.
EVOL	-	Computed value of volume effectiveness factor.
FA	-	Computed value of available freeboard.
FMIN	-	Computed value of minimum acceptable freeboard.
GMACT	-	Computed value of available metacentric height.
MA	-	First exponent used in the search.
MB	-	Second exponent used in the search.
MC	-	Third exponent used in the search.
MD	-	Fourth exponent used in the search.
MIX	-	Input indicator for whether or not the volume subroutine will be used.
MODE	-	Input indicator for which optimization scheme will be used.
N	-	Input number of loops to be evaluated.
NCPO	-	Computed number of chief petty officers.
NCREW	-	Computed number of enlisted men.
NOFF	-	Computed number of officers.
PC	3	Array which stores the input values of the propulsive coefficients for each of the required design speeds.
PCTAMO	-	Input value of percent cargo weight for ammunition.
PCTBRN	-	Input value of percent cargo weight for dry and refrigerated cargo.

Name	Dimension	Definition
PCTJP5	-	Input value of percent liquid cargo that is JP-5.
PUMPHP	-	Input value of transfer power required.
RKB	-	Computed height of ship's center of bouyancy.
RKG	-	Computed height of ship's center of gravity.
RL	-	Computed value of ship's length.
SHP	-	Computed value of maximum S.H.P..
SHPEND	-	Computed value of endurance S.H.P..
SHPREP	-	Computed value of replenishment S.H.P..
SHP20	-	Computed value of S.H.P. required to make 20 kts.
STOAMO	-	Input value of ammunition stowage factor.
STOBRN	-	Input value of dry and refrigerated cargo stowage factor.
T	-	Computed value of ship's draft.
TCOST	-	Computed value of 25 year life cycle cost.
TIME	4	Array which stores percent time each exponent will operate in the search.
TMAX	-	Input value of maximum allowable draft.
TRANWT	-	Input value of transfer equipment weight.
VEND	-	Input value of endurance speed.
VFULL	-	Input value of maximum speed.
VOLACT	-	Computed value of volume available for payload.
VOLAIR	-	Input of volume required by ship's aviation features.

Name	Dimension	Definition
VOLREQ	-	Computed value of volume required by the payload.
VOLT	-	Input of volume required by transfer equipment.
VREPLN	-	Input value of replenishment speed.
W	4	Array which stores the user weighting factors.
WPLD	-	Input value of required payload weight.
WTAIR	-	Input value of weight required by ship's aviation features.
WTAMMO	-	Input value of ship's ammunition weight.
WTCOMP	-	Computed value of the weight required by the ship's officers and crew and their effects.
WTFDWF	-	Computed value of feed water weight.
WTFUEL	-	Computed value of bunker fuel weight.
WTGRP	7	Array which stores computed values of the ship's seven weight groups.
WTLBOL	-	Computed value of lubrication oil weight.
WTPLD	-	Computed value of payload weight.
WTPTWR	-	Computed value of potable water weight.
WTSTOR	-	Computed value of stores weight.
XB	5	Array which stores independent variables of best design.
XMAX	5	Array which stores upper limits for independent variables.
XMIN	5	Array which stores lower limits for independent variables.
XPCT	-	Input value of the percent of the cargo which is liquid.
XV	5	Array which stores the independent variables during each design.

The following variable names appear in the main routine outside common storage.

Name Definition

AN - Stores number of loops as a real number.

CSTAR - Stores best value of COVERE.

I - Counter for the independent variable being updated.

IJ - Counter used when independent variables are placed in array XB.

IMA - Number of loops to be searched with the first exponent.

IMB - Number of loops to be searched with the second exponent.

IMC - Number of loops to be searched with the third exponent.

J - Counter for the number of trys to successfully update an independent variable.

L - Counter for the number of loops to be evaluated.

M - Value of the exponent in use.

NERR - Indicator for valid or invalid return from the subroutines.

TSQRD - Intermediate answer in the draft calculation.

XSAVE - Saves the value of the independent variable actually in use.

ZZZ - Number used in initializing the random number generator.

The following variable name appears in the input subroutine outside common storage.

Name Definition

I - Counter used in reading the input cards.

The following variable names appear in the design subroutine outside common storage.

Name		Definition
[illegible]	-	Intermediate result in the GM calculation.
DISLSP	-	Computed ship weight less payload weight.
DISP	-	Computed sum of the ship's seven weight groups.
GMMIN	-	Computed value of minimum acceptable metacentric height.
MOM1	-	Vertical moment of weight group one.
MOM2	-	Vertical moment of weight group two.
MOM3	-	Vertical moment of weight group three.
MOM4	-	Vertical moment of weight group four.
MOM5	-	Vertical moment of weight group five.
MOM6	-	Vertical moment of weight group six.
MOM7	-	Vertical moment of weight group seven.
MOMAIR	-	Vertical moment of aviation features.
MOMAMO	-	Vertical moment of ship's ammunition.
MOMCOM	-	Vertical moment of ship's complement.
MOMFDW	-	Vertical moment of feed water.
MOMFEL	-	Vertical moment of ship's fuel.
MOMMAR	-	Vertical moment of ship's margin weight.
MOMOIL	-	Vertical moment of lubricating oil.
MOMPLD	-	Vertical moment of ship's payload.
MOMPOW	-	Vertical moment of potable water.
MOMSTR	-	Vertical moment of ship's stores.
NERR	-	Indicator for valid or invalid return from this subroutine.
SG401	-	Computed portion of weight group four.
SG403	-	Computed portion of weight group four.
SG450	-	Computed portion of weight group four.

Name Definition

SGLLD - Computed portion of weight group five.

SGPLD - Computed portion of weight group five.

SGSHP - Computed portion of weight group five.

SHPFUL - Computed value of S.H.P. required for full speed.

TEST - Computed minimum acceptable payload.

VSQRTL - Computed value of speed-length ratio needed to enter powering subroutine.

WTMAR - Computed value of margin weight.

The following variable names appear in the volume subroutine outside common storage.

Name Definition

AM - Computed value of midship's area.

BLKR - Volume of boatswain's locker.

CMX - Computed value of midship's coefficient based on depth.

CPO - Computed number of chief petty officers (real).

DRYRM - Volume of drying room.

ELECSP - Volume of electrical shop.

EM - Computed number of enlisted men (real).

GALLEY - Computed volume of ship's galley.

GENLSP - Volume of general shops.

HBYSP - Volume of the hobby shop.

HD - Computed number of ship's heads.

MARMO - Volume of the master at arm's office.

MISSTR - Volume of miscellaneous store rooms.

NBK - Computed number of berths.

NCPOM - Computed number of CPO mess seats.

NEMM - Computed number of enlisted mess seats.

Name		Definition
[illegible]	-	[illegible] subroutine.
NLAV	-	Computed number of washroom sinks.
NSH	-	Computed number of showers.
NUR	-	Computed number of urinals.
NWC	-	Computed number of water closets.
ORDSP	-	Volume of the ordinance shop.
POSTO	-	Volume of the post office.
TRNOFF	-	Volume of the training office.
VAMMO	-	Computed volume required for cargo ammunition.
VBERTH	-	Computed volume of berthing spaces.
VCOBSP	-	Volume of the cobbler shop.
VCPOBK	-	Volume required by CPO berthing spaces.
VCPOM	-	Computed volume of CPO mess.
VDRY	-	Computed volume required for bulk cargo.
VEMBK	-	Computed volume for enlisted berting spaces.
VEMM	-	Computed volume of the enlisted mess.
VFUEL	-	Computed volume required for ship's fuel.
VGRDTL	-	Volume of the chain locker.
VHD	-	Computed volume of the ship's heads.
VJP5	-	Computed volume required by cargo JP-5.
VLADRY	-	Computed volume for the ship's laundry.
VLUBOL	-	Computed volume for ship's lubrication oil.
VMESS	-	Computed volume of messing facilities.
VOFICE	-	Volume required for office space.
VOL	-	Computed value of internal volume.
VOLENG	-	Computed volume required by engineering spaces.

Name Definition

VOLREQ - Computed volume required by [illegible].

VOLSTR - Volume required by storerooms.

VPASSG - Computed volume required for passageways.

VPLOIL - Computed volume required for cargo oil.

VSHOP - Computed volume required for shop spaces.

VSONR - Volume required for sonar spaces.

VSTGRR - Computed volume required for steering gear room.

VUPTK - Computed volume for uptake spaces.

VWATER - Computed volume required for feed and potable water.

The following variable names appear in the cost subroutine outside common storage.

Name Definition

COS1 - Computed cost of weight group one.

COS2 - Computed cost of weight group two.

COS3 - Computed cost of weight group three.

COS4 - Computed cost of weight group four.

COS5 - Computed cost of weight group five.

COS6 - Computed cost of weight group six.

COS7 - Computed cost of weight group seven.

SCOST - Computed sum of the costs of the seven weight groups.

SCPCO - Costs plus change order costs.

SCPDE - Costs plus design and construction costs.

SCPES - Costs plus escalation costs.

SCPM - Costs plus margin costs.

SCPP - Costs plus profit costs.

SCPPD - Costs plus post delivery costs.

Name   Definition

[illegible]   -   Costs plus quality [illegible].

The following variable names appear in the effectiveness subroutine outside common storage.

Name   Definition

BTFUEL - Computed fuel weight for between replenishment steaming.

EFF - Computed value of effectiveness.

NERR - Indicator for valid or invalid return from this subroutine.

REFUEL - Computed fuel weight for along-side replenishment steaming.

SHPR - Computed value of replenishment S.H.P..

TRFUEL - Computed fuel weight for transit to and from replenishment area.

The following variable names appear in the output subroutine outside common storage.

Name   Definition

I - Indicator for which part of the subroutine is to be used.

L - Stores the current value in the loop counter.

2. <u>Box Description</u>

The main or executive routine and all the subroutines of the AOX optimization program are subdivided into blocks of calculations. Each block or grouping of statements performs one or more distinct steps during the computation process. This breakdown simplifies making changes to the program within the established program logic. The blocks, called "boxes", are indicated by comment cards in the program listings (See Appendix E).

Main Routine:

Box 1 - Calls input subroutine.

Box 2 - Initializes variables [illegible] to be [illegible] prior to the first design loop.

Box 3 - Sets up loop counter.

Box 4-5 - Checks which exponent is to be used by the updating mechanism.

Box 6 - Sets up the variable counter within each loop.

Box 7 - Sets up counter for the number of design attempts per independent variable.

Box 8 - Performs the variable updating process and checks that the updated variable is within prescribed limits.

Box 9 - Calculates basic ship dimensions and coefficients and checks that design is within beam, draft, and freeboard limitations.

Box 10 - Checks whether volume subroutine should be called and makes call if necessary. Checks for adequate volume return. Calls cost and effectiveness subroutines and checks for proper return. Compares calculated value of cost effectiveness with best previous value.

Box 11 - Saves independent variables of most recent best design. Calls output subroutine to indicate improved design.

Box 12 - End point of inner design loop. Restores prior value of design variable if update did not result in an acceptable design. Checks if program is in the first loop.

Box 14 - Checks if all independent variables have been updated and if program has produced a CSTAR value during any previous design cycle.

Box 15 - End of design loop.

Box 16 - Calls output subroutine to indicate that the program is completed.

Box 17 - Calls output subroutine to indicate no successful design achieved from the input parameters.

Input Subroutine:

The input subroutine reads in the initial data and the residual resistance coefficients for the powering subroutine. The

subroutine then sets up the first page of output which lists design limitations and initial requirements (see sample output, Appendix F).

Design Subroutine:

Box 1 - Initializes error indicator to proper return value.

Box 2 - Calculates cubic number.

Box 7 - Calls powering subroutine for maximum speed S.H.P. and the S.H.P. required to make the endurance speed.

Box 8 - Calls powering subroutine for replenishment S.H.P. and adds to it the required transfer power.

Box 9 - Calculates weights for the standard seven weight groups, margin weight, and light ship displacement.

Box 10 - Calculates crew size, complement weight, and weights for ship's stores, potable water, reserve feed water, lubrication oil, and endurance fuel.

Box 11 - Checks for adequate displacement.

Box 12 - Calculates actual payload weight.

Box 13 - Checks that actual payload weight is 75% of the required payload weight or more.

Box 14 - Calculates minimum GM, KG, BM, KM, and actual GM.

Box 15 - Checks for adequate GM.

Box 18 - Provides for inadequate design return to main program.

Volume Subroutine:

Box 1 - Calculates internal volume below the main deck.

Box 2 - Calculates volume required for ship's stores.

Box 3 - Calculates volume required for enlisted and CPO berthing.

Box 4 - Calculates volume required for below decks sanitary facilities.

Box 5 - Calculates volume required for enlisted and CPO messing facilities.

Box 6 - Calculates volume required for below decks office and service space.

Box 7 - Calculates volume required for below decks passageways.

Box 8 - Calculates volume required by uptakes.

Box 9 - Calculates volume required by steering gear room.

Box 10 - Calculates volume required by below decks shops.

Box 11 - Provides fixed volume for chain locker.

Box 12 - Calculates volume required for ship's liquids.

Box 13 - Calculates volumes required for machinery spaces.

Box 14 - Calculates volume available for payload.

Box 15 - Calculates volume required for actual payload.

Box 16 - Checks for adequate volume for payload.

Box 17 - Provides for inadequate volume return.

Cost Subroutine:

Box 1 - Calculates basic aquisition cost based on standard weight groups.

Box 2 - Adds a percentage for margin.

Box 3 - Adds a percentage for design and construction costs.

Box 4 - Adds a percentage for escalation costs.

Box 5 - Adds a percentage for profit.

Box 6 - Adds a percentage for change order costs.

Box 7 - Adds a percentage for post delivery costs.

Box 8 - Adds a percentage for quality assurance costs

Box 9 - Adds a percentage for meeting shock requirements. Calculates annual operating costs and twenty-five year life cycle costs.

Effectiveness Subroutine:

Box 1 - Calculates endurance factor.

Box 2 - Calculates freeboard and payload factors.

Box 2A - Checks if volumes have been calculated and if necessary calculates a volume factor.

Box 3 - Checks which optimization scheme is to be utilized.

Box 4 - Calculates effectiveness as fixed number plus the sum of the effectiveness factors.

Box 5 - Calculates effectiveness as a fixed number less the sum of the absolute values of the effectiveness factors.

Box 6 - Checks that the effectiveness number is not less than or equal to zero.

Box 7 - Provides for error return to main program.

Box 8 - Evaluates cost effectiveness.

Box 9 - Checks that cost effectiveness is not zero and returns to main program.

Powering Subroutine:

The powering subroutine is the same as that used in Ref. (7) and is based on Taylor's Standard Series (Ref. (9)).

Random Number Generator:

The function subroutine used to generate the random numbers necessary for updating the independent variables is that used in Ref. (7) modified to ensure a zero return on the first call to the function.

Output Subroutine:

The output subroutine sets up the format for program output after the first page. It provides for listing each improvement on the initial design and indicates the final or optimum design.

APPENDIX C

Initial Requirements for this Study

The following initial input parameters are listed in the order presented in Table II.

1. Required Payload - 25,700 tons
2. Maximum Speed - 26 knots
3. Replenishment Speed - 20 knots
4. Endurance Speed - 17 knots
5. Endurance Range - 10,000 nautical miles
6. Armament Weight - 80 tons
7. Ammunition Weight - 70 tons
8. Aviation Features Weight - 841 tons
9. Transfer Equipment Weight - 1295 tons
10. Liquid Cargo - varies from 92% to 65%
11. JP-5 - 22.5% of liquid cargo
12. Cargo Ammunition Weight - varies from 6.7% to 27.6%
13. Bulk Cargo Weight - varies from 1.3% to 7.4%
14. Maximum Beam - 109.0 feet
15. Maximum Draft - 42.0 feet
16. Required Transfer Power - 5000 horse power

APPENDIX B

User Instructions

Prior to using the AOX program, the following data cards must be provided.

Card	Columns	Format	Data
1	7-12	F6.0	Initial displacement.
	16-20	F5.4	Initial prismatic coefficient.
	24-29	F6.4	Initial speed-length ratio.
	33-38	F6.4	Initial beam/draft.
	42-47	F6.3	Initial length/depth.
2	7-12	F6.0	Minimum displacement.
	16-20	F5.4	Minimum prismatic coefficient.
	24-29	F6.4	Minimum speed-length ratio.
	33-38	F6.4	Minimum beam/draft.
	42-47	F6.3	Minimum length/depth.
3	7-12	F6.0	Maximum displacement.
	16-20	F5.4	Maximum prismatic coefficient.
	24-29	F6.4	Maximum speed-length ratio.
	33-38	F6.4	Maximum beam/draft.
	42-47	F6.3	Maximum length/depth.
4	7-20 (two spaces between numbers)	F2.1	Values desired for time array.
	23-32 (two spaces between numbers)	I1	Search exponents.
	35-38	I4	Number of loops.
	42-46	F5.1	Maximum beam.
	50-53	F4.1	Maximum draft.
5	7-21 (one space between numbers)	F3.1	Four weighting factors.
	26	I1	Mode indicator.
	31	I1	Mix indicator.
6	7-9	F3.0	Maximum speed.
	12-14	F3.0	Replenishment speed.
	18-20	F3.0	Endurance speed.
	23-25	F3.2	Propulsive coefficient at max. speed.
	28-30	F3.2	Propulsive coefficient at replenishment speed.
	33-35	F3.2	Propulsive coefficient at endurance speed.

Card	Columns	Format	Data
7	7-12	F6.0	Required payload.
	15-18	F4.0	Armament weight.
	21-24	F4.0	Ammunition weight.
	25-30	F4.0	Aviation features weight.
	33-37	F5.0	Transfer equipment weight.
	40-46	F7.0	Volume required by transfer equipment.
	50-56	F7.0	Volume required for aviation features.
8	7-10	F4.3	Percent liquid cargo by weight.
	13-16	F4.3	Percent of liquid cargo for JP-5.
	19-22	F4.3	Percent cargo weight for ammunition.
	25-28	F4.3	Percent cargo weight for bulk cargo.
	31-35	F5.0	Transfer power.
	38-42	F5.1	Ammunition stowage factor.
	45-49	F5.1	Bulk cargo stowage factor.
9-1043	22-63	6F7.3	Taylor Standard Series residual resistance coefficients (See Ref. (7)).

Fortran Listings

```
      [illegible]
C BOX 1
      CALL I[illegible]T
C BOX 2
      [illegible] = [illegible]
      I[illegible] = [illegible]*TIME(1)
      I[illegible] = [illegible]*TIME([illegible])
      I[illegible]C = [illegible]*TIME([illegible])
      NERR = [illegible]
      C[illegible] = 1
      X[illegible](1) = XV(1)
      X[illegible](2) = XV(2)
      X[illegible](3) = XV(3)
      X[illegible](4) = XV(4)
      X[illegible](5) = XV(5)
      IJ = [illegible]
      ZZZ = [illegible](-1.[illegible])
      N[illegible] = [illegible]+1
C BOX 3
      DO 15[illegible] L =1,[illegible]
C BOX 4 - 5
      IF(L-I[illegible])[illegible]
[illegible]   [illegible] = [illegible]
      GO TO 6
[illegible]1  IF(L-I[illegible])[illegible]
4[illegible]  [illegible] = [illegible]
      GO TO 6
4[illegible]  IF(L-I[illegible]C)[illegible],4[illegible],[illegible]
44    [illegible] = [illegible]
      GO TO 6
45    [illegible] = [illegible]
C BOX 6
6     DO 1[illegible] I =1,[illegible]
      XSAVE = XV(I)
C BOX 7
      DO 12[illegible] J =1,[illegible]
C BOX [illegible]
[illegible]   X[illegible](I) = [illegible](I) + [illegible]
      IF(XV(I)-X[illegible](I))[illegible]
[illegible]   IF(X[illegible](I)-[illegible](I))[illegible]
C BOX [illegible]
[illegible]   C[illegible] = [illegible]
      [illegible] = [illegible]
      [illegible]L = [illegible]
      C[illegible] = ([illegible])/([illegible])
      I[illegible] = ([illegible](I))/([illegible])
```

```
      [illegible]
C     [illegible]
      IF([illegible])[illegible]
C     [illegible] L[illegible]T
      F[illegible] = [illegible].[illegible]
      F[illegible] = .[illegible]
C     [illegible]
      IF(F[illegible]-F[illegible])[illegible]
      CALL [illegible]I[illegible]([illegible])
      IF([illegible])1[illegible]
C   [illegible]X 1
1[illegible]  IF([illegible]Y-[illegible])1[illegible]
[illegible]1  CALL [illegible]L([illegible])
      IF([illegible]RR)1[illegible],1[illegible]
1[illegible]  CALL [illegible]ST
      CALL [illegible]FFECT([illegible])
      IF([illegible])12[illegible],1[illegible],1[illegible]
1     IF([illegible]-[illegible])1[illegible],[illegible],1[illegible]
C  BOX 11
11    C[illegible]T[illegible] = [illegible]
      CALL [illegible]T(2,L)
      DO 111 IJ =1,[illegible]
      X[illegible](IJ) = X[illegible](IJ)
11[illegible] CONTINUE
      GO TO [illegible]
C  BOX 12
12[illegible] CONTINUE
      XV(I) = [illegible]
      IF(L-1)14[illegible],14[illegible],1[illegible]
C  BOX 14
14    I-(I-[illegible])1[illegible],1+1,[illegible]+1
14[illegible] IF(IJ)1[illegible],[illegible]7[illegible],[illegible]
C  BOX 15
1[illegible]  CONTINUE
C  BOX 16
      CALL OUT([illegible],L)
      GO TO 2[illegible]
C  BOX 17
17    CALL OUT(1,L)
2[illegible]  CONTINUE
      END
```

```
[illegible]
[illegible]
C     READ INPUT CARDS
      READ(5,1) (YM(I),I=1,5)
      READ(5,1) (YMI[illegible](I),I=1,5)
      READ(5,1) (X[illegible]X(I),I=1,5)
1     FORMAT([illegible]X,F6.[illegible])
      READ(5,2) (TI[illegible]E(I),I=1,4),[illegible]
2     FORMAT(6X,F[illegible].1,2X,F[illegible],I1,[illegible],I1,[illegible]
     1I4,3X,F5.1,3X,F4.1)
      READ(5,3) (R(I),I=1,4),[illegible]
3     FORMAT(6X,F3.1,1X,F[illegible])
      READ(5,4) [illegible]
4     FORMAT([illegible]X,F[illegible],2X,F[illegible],2X,F[illegible])
      READ(5,5) [illegible]
5     FORMAT(3X,F6.[illegible],2X,F[illegible],2X,F[illegible],F5.[illegible],F7.[illegible],2X,F7.2)
      READ(5,6) XPIT,[illegible]
6     FORMAT(5X,F4.2,[illegible],F4.[illegible],2X,F[illegible],F[illegible].1)
      READ(5,7) (C[illegible](I),I=1,[illegible])
7     FORMAT([illegible]F7.[illegible])
C     SETUP [illegible] OUTPUT
      WRITE(6,1[illegible])
1[illegible]  FORMAT([illegible]X,[illegible]TI[illegible] ///)
      WRITE(6,1[illegible])
1[illegible]  FORMAT(7X,[illegible]INI[illegible])
      WRITE(6,1[illegible]) TIME
1[illegible]  FORMAT(7X,[illegible]TIME(1)=,F[illegible].1,[illegible]TIME([illegible])=,
     1F2.1,[illegible]TIME(4)=,F[illegible].1)
      WRITE(6,1[illegible]) [illegible]
1[illegible]  FORMAT(7X,[illegible]=,I1,[illegible]=,I[illegible]=,I[illegible]=,I[illegible],
     12H[illegible]=,I4)
      WRITE(6,1[illegible])
1[illegible]  FORMAT(7X,[illegible] INITIAL)
      WRITE(6,1[illegible]) [illegible](1),[illegible](1),X[illegible](1)
1[illegible]  FORMAT(2[illegible]X,F[illegible],[illegible]X,F[illegible],[illegible],F[illegible])
      WRITE(6,1[illegible])
1[illegible]  FORMAT(7X,[illegible] INITIAL)
      WRITE(6,1[illegible]7) [illegible](2),[illegible](2),[illegible](2)
1[illegible]  FORMAT([illegible]X,F[illegible],[illegible]X,F[illegible],[illegible]X,F[illegible])
      WRITE(6,1[illegible])
1[illegible]  FORMAT(7X,[illegible]/[illegible]T(L)[illegible] INITIAL)
      WRITE(6,[illegible]) [illegible](3),[illegible](3),[illegible]
1[illegible]  FORMAT([illegible]X,F[illegible],[illegible]X,F[illegible],[illegible])
      WRITE(6,[illegible])
1[illegible]  F[illegible] INITIAL)
      [illegible]
111   F[illegible]
```

```
[illegible]
      WRITE(6,11[illegible])
1[illegible]  FORMAT(7X,[illegible] I [illegible])
      WRITE(6,11[illegible]) [illegible]EL
11[illegible]  FORMAT(7X,[illegible]YL[illegible],I[illegible])
      WRITE(6,116) [illegible]FULL
11[illegible]  FORMAT(7X,1[illegible])
      WRITE(6,117) V[illegible]
11[illegible]  FORMAT(7X,[illegible]ENDURANCE[illegible],5X,F5.[illegible])
      WRITE(6,11[illegible]) [illegible]
11[illegible]  FORMAT(7X,[illegible]ENDURANCE SPEED[illegible],5X,F5.[illegible],7X,[illegible]KTS)
      WRITE(6,11[illegible])
11[illegible]  FORMAT(7X,[illegible]OF [illegible] 10000 [illegible]MILES)
      WRITE(6,121) [illegible]
121   FORMAT(7X,[illegible]PT,1[illegible],F4.[illegible],[illegible]LTONS)
      WRITE(6,122) [illegible]TA[illegible]
12[illegible]  FORMAT(7X,13H[illegible]ITION[illegible],11[illegible],F[illegible],[illegible]TONS)
      WRITE(6,12[illegible]) [illegible]TAI[illegible]
12[illegible]  FORMAT(7X,1[illegible]ITIO[illegible]T,1[illegible],F[illegible],[illegible]X,[illegible]TONS)
      WRITE(6,12[illegible]) T[illegible]
12[illegible]  FORMAT(7X,1[illegible]T[illegible]PT[illegible]T,5[illegible],F5.[illegible],[illegible]X,[illegible]TONS)
      WRITE(6,1[illegible]5) [illegible]PCT
12[illegible]  FORMAT(7X,[illegible]LI[illegible]ES ,F4.[illegible],21H OF TOTAL PAYLOAD [illegible]T.)
      WRITE(6,12[illegible]) PCTUP[illegible]
12[illegible]  FORMAT(7X,1[illegible]UPE[illegible],F4.[illegible],2[illegible] OF LI[illegible]T.)
      WRITE(6,127) PCT[illegible]
127   FORMAT(7X,1[illegible]C[illegible],F4.[illegible],21[illegible] OF TOTAL [illegible]YL[illegible]T.)
      WRITE(6,128) PCT[illegible]
12[illegible]  FORMAT(7X,17HDRY CARGO EQUALS ,F4.3,21H OF TOTAL PAYLOAD [illegible]T.)
      WRITE(6,12[illegible])
12[illegible]  FORMAT(7X,[illegible]ILIA[illegible] INPUT [illegible])
      WRITE(6,1[illegible]) [illegible]
13[illegible]  FORMAT(7X,[illegible]AXI[illegible] ALLO[illegible],[illegible],F[illegible].1,[illegible])
      WRITE(6,131) T[illegible]
131   FORMAT(7X,[illegible]XI[illegible] ALLO[illegible]T,[illegible],F4.1,[illegible])
      WRITE(6,132) P[illegible]HP
13[illegible]  FORMAT(7X,14H[illegible]SFER [illegible],14X,F[illegible],[illegible],4X,[illegible]HP)
      WRITE(6,1[illegible]3) MODE
13[illegible]  FORMAT(7X,17[illegible]TI[illegible]ZATI[illegible],11X,I1)
      WRITE(6,1[illegible]4) [illegible]IX
13[illegible]  FORMAT(7X,1[illegible]IC[illegible]T[illegible],[illegible],I1)
      WRITE(6,1[illegible])
1[illegible]  FORMAT([illegible],17H[illegible]EIGHT[illegible]/1[illegible]X,[illegible]FUEL,13X,F[illegible].1/1[illegible]X,
     19HFRE[illegible],14X,F[illegible].1/1[illegible],1[illegible]YL[illegible]T.,[illegible]X,F[illegible].1/1[illegible],1[illegible]YL[illegible]
     2L.,1[illegible]X,F3.1/)
      RETURN
      END
```

```
C     BOX 1
      [illegible] = [illegible]
C     BOX 2
      C[illegible] = ([illegible]L [illegible])/1[illegible].
C     BOX 7
7     CALL [illegible](XV([illegible]),[illegible]([illegible]),[illegible]([illegible]),[illegible]L,[illegible](1),[illegible]([illegible]),[illegible])
      VS[illegible]RTL = [illegible]/[illegible]T([illegible]L)
      CALL RES[illegible]ST(XV(4),[illegible](2),[illegible]RTL,[illegible]L,[illegible](1),[illegible],[illegible]C([illegible]),[illegible])
C     BOX 3
      VS[illegible]RTL = [illegible] /[illegible]T([illegible]L)
      CALL RESIST(XV(4),[illegible](2),[illegible]RTL,[illegible](1),[illegible](2),[illegible]20)
      [illegible] = [illegible] + [illegible]
C     BOX 9
C     GROUP 1 HULL [illegible]
      WTGRP(1) = (.[illegible] + .[illegible]*(XV(1)-1[illegible].))[illegible] + .[illegible]11*([illegible].)
     1+[illegible]62[illegible].*[illegible] + [illegible].*(XV([illegible])-1[illegible].) [illegible]
C     GROUP 2 PROPULSION
      IF ([illegible]P[illegible]L - [illegible]) [illegible],[illegible],21
      SHP = SHP[illegible]
      GO TO 22
21    SHP = [illegible]PF[illegible]L
22    WTGRP(2) = .[illegible]71*SHP + [illegible]1.
C     GROUP 3 ELECTRIC PLANT
      WTGRP(3) = .[illegible]5*(SHP/1[illegible].) + [illegible].
C     GROUP 4 COMMUNICATION [illegible] CONTROL
      SG4[illegible]1 = .11[illegible]*(C[illegible]/1[illegible].) + 1[illegible].[illegible]
      SG4[illegible] = .[illegible]14[illegible]*(C[illegible]/[illegible].) + [illegible]
      SG4[illegible] = .[illegible]1[illegible]*(SG[illegible] +SG[illegible])[illegible].
      WTGRP(4) = 145.[illegible] + SG4[illegible]1 + SG4[illegible] + SG4[illegible]
C     GROUP 5 AUXILIARY EQUIPMENT
      SGL[illegible] = 91.1[illegible]*[illegible]T(C[illegible]/1[illegible].)
      SG[illegible]L[illegible] = .[illegible]*[illegible]CT[illegible]PL[illegible]
      SGSHP = [illegible].5[illegible]*SQRT(SHP/1[illegible].)
      WTGRP(5) = 1.[illegible]*(SGL[illegible] + [illegible]PL[illegible] + SGSH[illegible] + T[illegible])
C     GROUP 6 OUTFIT
      WTGRP(6) = [illegible].[illegible]*(C[illegible]/[illegible].) + [illegible].
C     GROUP 7 ARMAMENT
      WTGRP(7) = [illegible]T
C     TOTALS AND [illegible]
      [illegible] = WTGRP(1) + WTGRP(2) + WTGRP(3) + WTGRP(4) + WTGRP(5)
     1 + WTGRP(6) + WTGRP(7)
      [illegible] = .[illegible]
      [illegible] = [illegible]
C     BOX [illegible]
C     [illegible] SIZE
```

```
      [illegible] = ( [illegible]
C     [illegible]
      TOT[illegible] = .[illegible]
C     POTA[illegible] [illegible]
      [illegible] = .13[illegible]
C     [illegible]
      TFD[illegible] = [illegible].[illegible](S[illegible]/[illegible] .)
C     LUBRICATI[illegible] [illegible]L
      TL[illegible]L = .[illegible](S[illegible]/10[illegible] .)
C     SHIP [illegible]L
      IF(S[illegible]-14[illegible] .)[illegible],1[illegible]
1[illegible]  WTF[illegible]L = 52[illegible].[illegible]
C     DISPLACEMENT LESS PAYL[illegible]
      DISLCD = [illegible] + [illegible] + [illegible] - [illegible] + [illegible] +
     1 WTF[illegible] + [illegible] + WTF[illegible]L
C BOX 11
      IF (X[illegible](1) - DISLCD)[illegible],15[illegible]
C BOX 12  COMPUTED PAYLOAD
12    [illegible]TPLD = [illegible](1) - [illegible]
C BOX 13
      T[illegible]T = .7[illegible]
      IF ([illegible]TPLD - [illegible]T)1[illegible]
C BOX 14
C     [illegible]
14[illegible] [illegible] = .[illegible]
C     CALCULATION OF ACTU[illegible]L [illegible]
      [illegible] = .5[illegible]T[illegible](1)
      [illegible]2 = .[illegible]T[illegible]( )
      [illegible] = .74[illegible]TG[illegible]
      [illegible] = .7[illegible]
      [illegible]5 = .73[illegible]
      [illegible]6 = .57[illegible]T[illegible]P([illegible])
      [illegible]7 = [illegible].[illegible](7)
      [illegible] = .[illegible]
      [illegible] = 1.[illegible]
      [illegible] = 1.1[illegible]
      [illegible] = .[illegible]T[illegible]
      [illegible]STP = .[illegible]TOT[illegible]
      [illegible]P[illegible] = .[illegible]
      [illegible]F[illegible] = .[illegible]
      [illegible]OIL = .[illegible]L[illegible]
      [illegible]FEL = .[illegible]TF[illegible]L
      [illegible]PL = (.5 -(.[illegible](T)) [illegible]
      R[illegible] = ( [illegible] + [illegible] + [illegible] +
     1 [illegible] + [illegible]
     [illegible] + [illegible])/ [illegible](1)
C     [illegible]
      C[illegible] = [illegible].[illegible]([illegible]) - [illegible]
      [illegible] = [illegible](.[illegible] + .[illegible])
      [illegible] = ([illegible] - [illegible])/[illegible](1)
```

```
      NTED =
C  BOX 1 HULL VOLUME
      VOL = C[illegible]
      VOLSTR = (72.[illegible])/.7
C  BOX 3 [illegible]
      VCREW = 21*[illegible]
      EM = NCRT
      VCRTOT = VCR[illegible]
C  BOX 4 [illegible]
      CPO = NCPO
      HMC = (EM/28.[illegible]) + (C[illegible]/1[illegible]) + [illegible].
      HU = ([illegible]) + ([illegible]) + [illegible].
      HLAV = (EM/[illegible]) + ([illegible]) + [illegible].
      HD = HMC + [illegible] + [illegible] + [illegible]
      VHD = 17.[illegible]
C  BOX 5 VOL[illegible] LISH[illegible]
      NCPO = .[illegible]
      VCPOT = 1[illegible]
      GALLEY = [illegible]
      VMESS = GALLEY + [illegible]
C  BOX 6 OFFICE AND SERVICE [illegible]
      VLAUNDY = 12.[illegible]
      VCORSP = 1.4[illegible]
      TRNOFF = [illegible].
      PLKR = [illegible].
      [illegible] = 7[illegible].
      DRYRM = 1[illegible].
      DLSTR = [illegible].
      [illegible] = [illegible].
      VOFICE = [illegible]
     1 DRYRM + [illegible]
C  BOX 7 [illegible]
      [illegible]
      VM[illegible] = [illegible]
C  BOX 8 [illegible]
      VST[illegible] = [illegible]
```

```
C      [illegible]
       [illegible] = [illegible]
C      [illegible]
       [illegible] = [illegible]
       [illegible] = ( [illegible] + [illegible] ) [illegible]
       [illegible] = [illegible]
       [illegible] = [illegible]
C      [illegible] 15 [illegible]
       V[illegible] = ( [illegible] / [illegible] + [illegible] ) [illegible]
C      [illegible]
       V[illegible] = VOL - [illegible] - [illegible] - [illegible] - [illegible] - [illegible] - [illegible] -
      1V[illegible] - [illegible] - [illegible] - [illegible] - [illegible] - [illegible] - V[illegible] - V[illegible]
C      [illegible]
       VOL[illegible] = [illegible] ( [illegible] - [illegible] ) [illegible]
       [illegible] = [illegible]
       [illegible] = [illegible]
       V[illegible] = [illegible]
       [illegible] = [illegible] - [illegible] - [illegible]
C[illegible] 16 VOLUME [illegible] CHECK
       IF( [illegible] - [illegible] ) [illegible]
1[illegible]    CONTINUE
       [illegible]
C      [illegible] 17 [illegible]
1[illegible]    [illegible] = [illegible]
[illegible]    RETURN
       END
```

```
C   OX 1 [illegible] COST
      C[illegible]1 = [illegible].[illegible]T[illegible](1)
      C[illegible]2 = [illegible].[illegible]T[illegible](2)
      COS3 = [illegible].[illegible]TGRP(3)
      COS4 = [illegible].[illegible]TGRP(4)
      COS5 = [illegible].[illegible]TGRP(5)
      COS6 = [illegible].[illegible]TGRP(6)
      COS7 = [illegible].[illegible]TGRP(7)
      SCOST = COS1 + COS2 + COS3 + COS4 + COS5 + COS6 + COS7
C   OX 2 [illegible]ST PLUS [illegible]
      SCP[illegible] = 1.[illegible]*SCOST
C   OX 3 [illegible] PLUS [illegible]
      SCPRE = 1.1[illegible]*SCP[illegible]
C   OX 4 ABOVE PLUS PCT FOR ESCALATION
      SCPE[illegible] = 1.[illegible]*SCP[illegible]
C   OX 5 ABOVE PLUS PROFIT
      SCP[illegible] = 1.[illegible]*SCP[illegible]
C   OX 6 ABOVE PLUS [illegible]
      SCPC = 1.[illegible]
C   OX 7 ABOVE PLUS [illegible]
      SCPPP = 1.[illegible]
C   OX 8 ABOVE PLUS PCT FOR QUALITY [illegible]
      SCPQA = 1.[illegible]*SCP[illegible]
C   OX 9 ABOVE PLUS PCT FOR [illegible]
      ACOST = 1.[illegible]*SCP[illegible]
      [illegible]PCT = (54.[illegible] + [illegible].[illegible]*C[illegible])*[illegible].
      TCOST = 1[illegible]*([illegible] + [illegible])
      RETURN
      END
```

```
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
C     [illegible]
      [illegible]
      [illegible] = [illegible]
C     [illegible]
      [illegible] = (((  T[illegible]L [illegible])/[illegible]) [illegible]
C     [illegible]
      [illegible] = [illegible]
      [illegible] = (( T[illegible])/[illegible] 1.) [illegible] /[illegible].)-[illegible])
C     T[illegible]L
      [illegible] = [illegible] L [illegible]
C     [illegible]
      [illegible] = (( [illegible])/[illegible] (1)
C     [illegible]
      [illegible] = (( [illegible])/[illegible] ( )
      [illegible] = (( [illegible] LD)/ [illegible] (C)
C     [illegible]
      IF( [illegible]
      [illegible] = ( [illegible] )/[illegible]( )
      [illegible]
C     [illegible]
      [illegible]L = [illegible]
      IF ( [illegible] )[illegible]
C     [illegible] A
      [illegible] = [illegible]
      GO T[illegible]
C     [illegible] B
      [illegible] = [illegible] ( [illegible]
C     [illegible]
      IF ( [illegible] )[illegible]
C     [illegible]
      [illegible] = [illegible]
      [illegible]
C     [illegible]
      [illegible] = T[illegible]/[illegible]
C     [illegible]
      IF ( [illegible] )[illegible]
      CONT[illegible]
      RET[illegible]
      [illegible]
```

```
[illegible]
      FORMAT(1H1,5X,[illegible] FOLLO[illegible] THUS FA[illegible]/)
[illegible]
      WRITE(6,2[illegible])
[illegible]
```

[illegible]

```
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]L,[illegible]T
      [illegible]EF(II,JJ,[illegible])=[illegible](II-1)[illegible](J[illegible]-1)+
      X[illegible]EFF(II,JJ,[illegible])=[illegible]+[illegible]FF(II,JJ,[illegible])
      CONTINUE
C     COMP[illegible]TATI[illegible] [illegible]L [illegible]
      C[illegible]=C[illegible]
      IF(C[illegible]-1,[illegible])[illegible]
[illegible]   [illegible]=
      [illegible]=C[illegible]-1.
      GO TO [illegible]
      IF(C[illegible]-[illegible])[illegible]
[illegible]   [illegible]=1
      C[illegible]=C[illegible]-[illegible]
      GO TO [illegible]
[illegible]   IF(CV[illegible]-[illegible])[illegible]
[illegible]   [illegible]=[illegible]
      CV[illegible]=C[illegible]-[illegible]
      [illegible]
[illegible]   IF(C[illegible]-[illegible])[illegible]
[illegible]   [illegible]=[illegible]
      CV[illegible]=C[illegible]-4.
      [illegible]4
[illegible]   [illegible]=[illegible]
      [illegible]=C[illegible]-[illegible]
      IF([illegible])[illegible]
[illegible]   I=[illegible]
      [illegible]
[illegible]   I=2
[illegible]   LL=[illegible]
      [illegible]LL=[illegible]
      [illegible]L=1[illegible]-[illegible]LL
      IF([illegible]L-[illegible])[illegible]
1     J=LL-[illegible]
      GO TO 1[illegible]
1[illegible]  J=LL-[illegible]
1[illegible]  K=[illegible](L+[illegible])-[illegible]
      L=[illegible]FF(I,[illegible])
      L=L+[illegible]
      [illegible]=[illegible](L)
      L=[illegible](I,[illegible])
      L=L+[illegible]
      [illegible](L)
      L=[illegible](I+[illegible])
      L=L+[illegible]
      [illegible](L)
```

[illegible]

```
PARAMETERS CONTROLLING THE EXPONENTIAL SEARCH
TIME(1)=.2   TIME(2)=.4   TIME(3)=.[illegible]   TIME(4)=.[illegible]
MA=1   MB=3   MC=5   ME=7   N= 500
DISPLACEMENT ,  MINIMUM    MAXIMUM    INITIAL
                45000.     60000.     52000.
CP           ,  MINIMUM    MAXIMUM    INITIAL
                .4800      .7000      .5620
V/SQRT(L)    ,  MINIMUM    MAXIMUM    INITIAL
                0.7700     0.9700     0.9220
B/T          ,  MINIMUM    MAXIMUM    INITIAL
                2.2500     3.7500     2.7220
L/D          ,  MINIMUM    MAXIMUM    INITIAL
                10.500     14.000     11.900

INITIAL REQUIREMENTS
PAYLOAD                       25700.      TONS
MAXIMUM SPEED                 26.         KTS
REPLENISHMENT SPEED           20.         KTS
ENDURANCE SPEED               17.         KTS
ENDURANCE RANGE               10000       MILES
ARMAMENT                      80.         TONS
AMMUNITION WT                 70.         TONS
AVIATION WTS                  841.        TONS
TRANSFER EQUIPMENT            1295.       TONS
LIQUID CARGO EQUALS .920 OF TOTAL PAYLOAD WT.
JP5 EQUALS .225 OF LIQUID CARGO WT.
CARGO AMMO. EQUALS .063 OF TOTAL PAYLOAD WT.
DRY CARGO EQUALS .017 OF TOTAL PAYLOAD WT.
AUXILIARY INPUT DATA
MAXIMUM ALLOWABLE BEAM            109.0     FT
MAXIMUM ALLOWABLE DRAFT           42.0      FT
TRANSFER POWER                    5000.     HP
OPTIMIZATION MODE                 1
CARGO MIX INDICATOR               1
WEIGHTING FACTORS
        SHIPS FUEL                1.0
        FREEBOARD                 1.0
        PAYLOAD WT.               5.0
        PAYLOAD VOL.              1.0
```

1. [illegible] 1
DISPLACEMENT(FL)=52[illegible] TONS CP=.562 V/S[illegible]L=.[illegible] B/T=2.722 L/D=11.[illegible]

2. MAIN DIMENSIONS
LENGTH=795.2 FT BEAM=106.7 FT DRAFT=39.2 FT DEPTH=66.8 FT

3. FORM COEFFICIENTS
CB= .5469 CP= .5620 CM= .9732 CV= .00362 CW= .7334

4. PROPULSION DATA

MAXIMUM SHP	85831.
ENDURANCE SHP	19042.
REPLENISHMENT SHP	37541.

5. WEIGHTS

GROUP 1 HULL STRUCTURE	12031.	TONS
GROUP 2 PROPULSION	1405.	TONS
GROUP 3 ELECTRIC PLANT	365.	TONS
GROUP 4 COMM. AND CONT.	226.	TONS
GROUP 5 AUXILIARY SYSTEMS	2660.	TONS
GROUP 6 OUTFIT AND FURN.	1620.	TONS
GROUP 7 ARMAMENT	80.	TONS
LIGHT SHIP DISPLACEMENT	19123.	TONS

SHIPS OFFICERS, CREW AND EFFECTS	63.55	TONS
SHIPS AMMUNITION	70.00	TONS
SHIPS STORES	203.32	TONS
AVIATION FEATURES	841.00	TONS
POTABLE WATER	87.74	TONS
RESERVE FEED WATER	187.11	TONS
SHIPS LUBRICATING OIL	21.46	TONS
SHIPS FUEL OIL	4230.02	TONS
FUEL OIL REQUIRED FOR MISSION	3086.58	TONS

5A. VOLUMES
REQUIRED PAYLOAD VOLUME 1217879. FT3 AVAILABLE 1280715. FT3

6. PAYLOAD CAPACITY
TOTAL PAYLOAD (FUEL, STORES, AMMO) 27167. TONS

7. STABILITY DATA (NO FREE SURFACE CORRECTION)
KB=22.90 FT KM=24.90 FT KG=32.45 FT GM=15.35 FT

8. COMPLEMENT, OFFICERS 32 CPO 26 ENLISTED 526

9. ECONOMIC DATA

ACQUISITION COST	60194112.	DOLLARS
ANNUAL OP. COST	7032871.	DOLLARS
25 YEAR COST	170062176.	DOLLARS

10. EFFECTIVENESS, FUEL, FREEBD, PAYLD WT, PAYLD VOL, COST/E

FUEL	FREEBD	PAYLD WT	PAYLD VOL	COST/E
1.99	0.99	5.59	0.13	6467795.000

```
THE FOLLOWING ARE THE BEST RESULTS THUS FAR

1. RANDOM VARIABLES, LOOP NUMBER  392
DISPLACEMENT(FL)=49614.TONS CP=.625 V/SQRTL=.395 B/T=2.448 L/D=13.02

2. MAIN DIMENSIONS
LENGTH=844.6 FT BEAM= 90.7 FT DRAFT=37.1 FT DEPTH=64.9 FT

3. FORM COEFFICIENTS
CB= .6113  CP= .6247  CM= .9785  CV= .00288  CW= .7615

4. PROPULSION DATA
MAXIMUM SHP             87827.
ENDURANCE SHP           18775.
REPLENISHMENT SHP       36893.

5. WEIGHTS
GROUP 1 HULL STRUCTURE       11546. TONS
GROUP 2 PROPULSION            1415. TONS
GROUP 3 ELECTRIC PLANT         365. TONS
GROUP 4 COMM. AND CONT.        222. TONS
GROUP 5 AUXILIARY SYSTEMS     2610. TONS
GROUP 6 OUTFIT AND FURN.      1442. TONS
GROUP 7 ARMAMENT                80. TONS
LIGHT SHIP DISPLACEMENT      18387. TONS

SHIPS OFFICERS, CREW AND EFFECTS    58.21 TONS
SHIPS AMMUNITION                    70.00 TONS
SHIPS STORES                       191.20 TONS
AVIATION FEATURES                  841.00 TONS
POTABLE WATER                       80.33 TONS
RESERVE FEED WATER                 191.46 TONS
SHIPS LUBRICATING OIL               21.96 TONS
SHIPS FUEL OIL                    4090.75 TONS
FUEL OIL REQUIRED FOR MISSION     2826.53 TONS

5A. VOLUMES
REQUIRED PAYLOAD VOLUME 1228169. FT3 AVAILABLE 1228233. FT3

6. PAYLOAD CAPACITY
TOTAL PAYLOAD (FUEL, STORES, AMMO)  25682. TONS

7. STABILITY DATA (NO FREE SURFACE CORRECTION)
KB=20.95 FT  KM=18.25 FT  KG=32.00 FT  GM= 7.20 FT

8. COMPLEMENT, OFFICERS  29    CPO  24    ENLISTED   482

9. ECONOMIC DATA
ACQUISITION COST   58401216.  DOLLARS
ANNUAL OP. COST     6484718.  DOLLARS
25 YEAR COST      159705984.  DOLLARS

10. EFFECTIVENESS: FUEL, FREEBD, PAYLD WT, PAYLD VOL,    COST/E
                   2.18    1.58    -0.06        0.00     5123016.000

PROGRAM COMPLETED

THIS PAGE LISTS OPTIMUM DESIGN
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NO INITIAL SOLUTION FOUND AFTER 25 ATTEMPTS

THE FOLLOWING VALUES ARE IN COMMON STORAGE

1. RANDOM VARIABLES
DISPLACEMENT(FL)=58000.TONS CP=.590 V/SQRTL=.900 B/T=2.600 L/D=10.90

2. MAIN DIMENSIONS
LENGTH=834.6 FT BEAM=104.8 FT DRAFT=40.3 FT DEPTH=70.7 FT

3. FORM COEFFICIENTS
CB= .5756  CP= .5900  CM= .9756  CV= .00349  CW= .7447

4. PROPULSION DATA
MAXIMUM SHP             93962.
ENDURANCE SHP           20691.
REPLENISHMENT SHP       40205.

5. WEIGHTS
GROUP 1 HULL STRUCTURE        13237. TONS
GROUP 2 PROPULSION             1444. TONS
GROUP 3 ELECTRIC PLANT          367. TONS
GROUP 4 COMM. AND CONT.         230. TONS
GROUP 5 AUXILIARY SYSTEMS      2670. TONS
GROUP 6 OUTFIT AND FURN.       1751. TONS
GROUP 7 ARMAMENT                 80. TONS
LIGHT SHIP DISPLACEMENT       20569. TONS

SHIPS OFFICERS, CREW AND EFFECTS   69.56 TONS
SHIPS AMMUNITION                   70.00 TONS
SHIPS STORES                      227.93 TONS
AVIATION FEATURES                 841.00 TONS
POTABLE WATER                      95.77 TONS
RESERVE FEED WATER                204.84 TONS
SHIPS LUBRICATING OIL              23.49 TONS
SHIPS FUEL OIL                   5043.62 TONS
FUEL OIL REQUIRED FOR MISSION      14.00 TONS

5A. VOLUMES
REQUIRED PAYLOAD VOLUME 2347016. FT3 AVAILABLE 1668672. FT3

6. PAYLOAD CAPACITY
TOTAL PAYLOAD (FUEL, STORES, AMMO)  30854. TONS

7. STABILITY DATA (NO FREE SURFACE CORRECTION)
KB=23.19 FT  KM=22.83 FT  KG=37.39 FT  GM= 8.63 FT

8. COMPLEMENT, OFFICERS  35    CPO  29    ENLISTED   575

9. TOTAL ACQUISITION COST  *********  DOLLARS

10. EFFECTIVENESS, FUEL, FREEBD, PAYLD WT, PAYLD VOL,   COST/E
                   *****   -0.00   *****      0.00     *********
```